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STACKS AND NOTCHES AT HOPEWELL ROCKS, NEW BRUNSWICK, CANADA

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ABSTRACT

Spectacular rock formations have developed in coarse, poorly sorted conglomerates and arkosic sandstones at Hopewell Rocks in the Bay of Fundy, which has the largest tidal range in the world. The average gradient of the shore platform is 3.2°, although it varies because of slight differences in rock hardness. Schmidt Rock Test Hammer measurements show that the rock is generally no more resistant in 16 stacks and in one stack-arch than in the adjacent platform and cliff. Most stacks, arch-tunnels and caves in this area result from dissection of the rock mass along prominent, well-spaced joint planes. Old photographs suggest that the stacks at Hopewell Rocks may have developed in the last 100 to 250 years. Notches are ubiquitous at the cliff foot, and they are responsible for the characteristic mushroom-shaped appearance of the stacks. Although there is no consistent relationship between the depth of notches on the seaward and landward sides of the stacks, the notches are at higher elevations on the seaward side. The deepest part of most notches is a little below the mean high tidal level, although several are up to 1 or 2 m below it, especially on the landward side of stacks. Stack morphology and notch depth change in a fairly predictable manner through time, as the stacks become increasingly isolated from the cliff. © 1998 John Wiley & Sons, Ltd.

KEY WORDS: rock coasts; Bay of Fundy; shore platforms; stacks; notches; tidal range

INTRODUCTION

The scenery of a rock coast is the product of a combination of elements including: the morphology of the hinterlands; the structure and hardness of the rocks; wave and tidal environments; changes in relative sea level; and present and past climates. These factors provide infinite variation to the basic geotectonic form. Coastal erosional processes are very sensitive to variations in rock structure and hardness. Small bays and narrow gorges develop along joint and fault planes, and in the fractured and crushed rock produced by faulting. Stacks, arches, caves and narrow inlets, which are often found in close association with each other, form on coasts that have well-defined planes of weakness. The rock must also be strong enough to stand as high, near-vertical slopes, however, and as the roofs of caves, tunnels and arches. Therefore, these features are less likely to develop in very weak rock types, or in rocks with a very dense joint pattern (Trenhaile, 1987). The purpose of this study was to determine the effect of a very large tidal range, and the role of rock structure and variations in rock hardness on the nature and development of a rock coast in the Bay of Fundy.

THE STUDY AREA

Hopewell Rocks Provincial Park near Moncton in the Bay of Fundy probably represents Canada's best example of an association of erosional features cut along lines of structural weakness (Figure 1). Tides in the Bay of Fundy are resonantly amplified and they are the largest known on Earth. The tidal range for average tides is 10·7 m at Hopewell Rocks, and it averages 14·7 m for the large or spring tides, although it can be several metres higher during storms (Figure 2). Coastal processes are therefore dominated by tidal variations in water level and strong tidally generated currents. Wave height decreases eastwards in the Bay of Fundy. The study area runs

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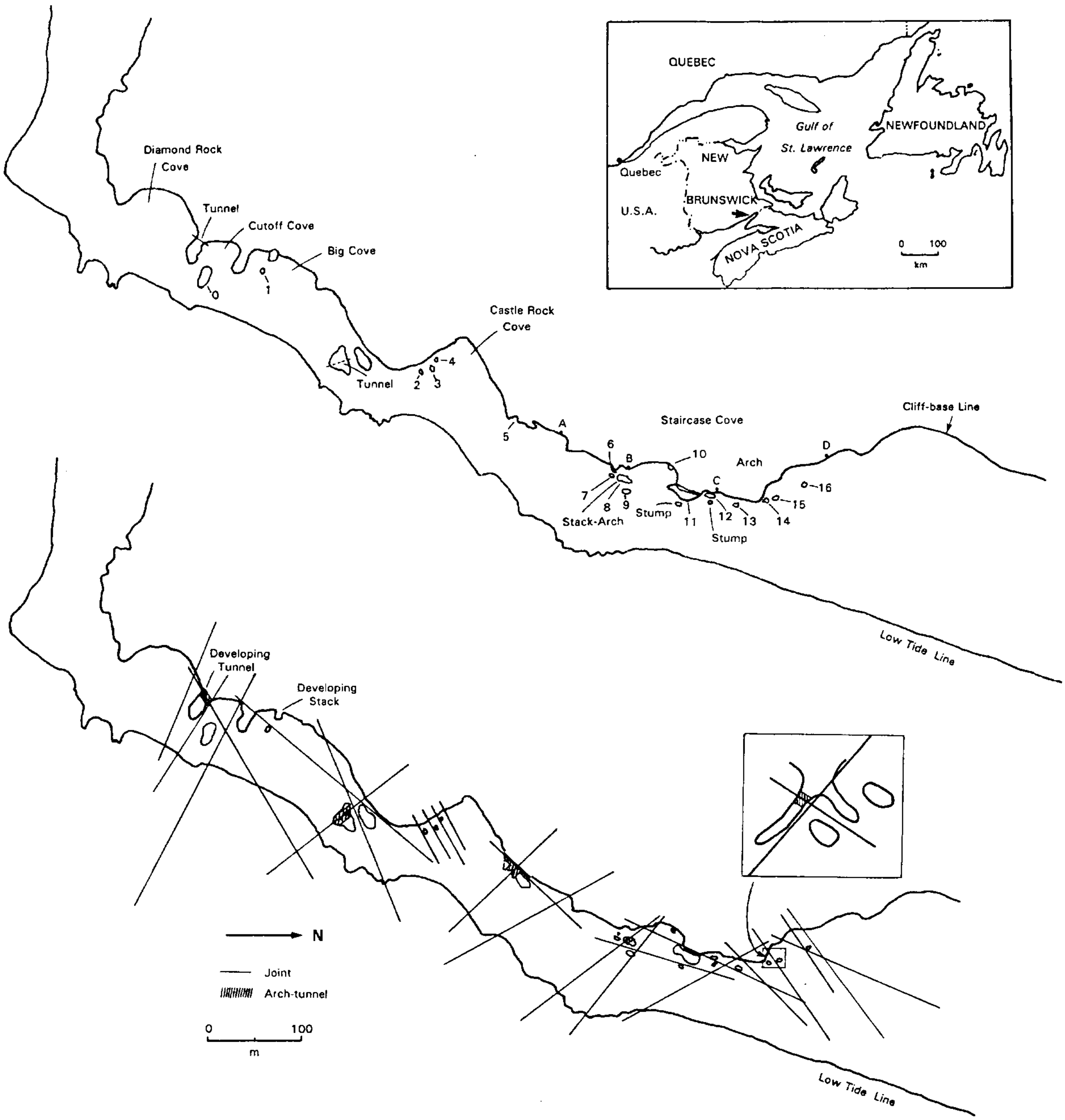

Figure 1. The study area and the effect of some prominent joints on coastal features.

approximately north–south, and it experiences refracted waves that are generated by prevailing westerly winds blowing along the axis of the Bay. Waves generated by easterly and northeasterly winds travel over fetch distances that are less than 10 km. Because of the high tidal range, wave energy is expended over a considerable range of elevations, and the effect of waves and tides is further restricted by the presence of shorefast ice from January to April.

The rocks in the study area belong to the Hopewell Conglomerate and Maringouin Formations of the Carboniferous (Mississippian) Hopewell Group (Poll,1973). They consist of arkosic sandstone and coarse, poorly sorted conglomerates, in which subangular, generally pebble–cobble clasts of granite, gneiss and volcanic rocks predominate. Natural zones of weakness are created in places by fairly thin bands of sandstone

(a)

(b)

Figure 2. Staircase Cove at low and high tide, looking south. Stack-arch 8 is to the left of the centre of the photographs and has trees growing on top of it. Stacks 6 and 7 are to the right of the stack-arch and part of stack 9 appears to the left.

and siltstone, and there are widely spaced joints oriented roughly parallel and perpendicular to the shore. There are three joint surface concentrations. The dominant set (J1) strikes 42° and dips 83° towards the southeast. The second most important set (J2) strikes 98° and is vertically dipping. The third set (J3) strikes 163° and dips 84° to the west. Bedding planes strike 148° and the strata have an average dip of 36° to the northeast, although the beds are almost vertical in some places. The bedding and J1 joint orientations are generally fairly consistent, whereas J2 and J3 orientations are more variable (Figure 3) (Jacques, Whitford and Associates, 1987).

The rocky coast at Hopewell Rocks is only about 1 km in length, but it contains approximately 16 stacks, several future stacks that are slowly becoming detached from the cliff, a wide stack with an arch cut through it (stack-arch), four arch-tunnels and about 17 marine caves. The cliff decreases in height from about 30–40 m in the south to 10–15 m in the north, and there is a similar decline in the height of the stacks, although they are generally a few metres lower than the cliff. In front of the cliff there is a wide shore platform, which is covered in

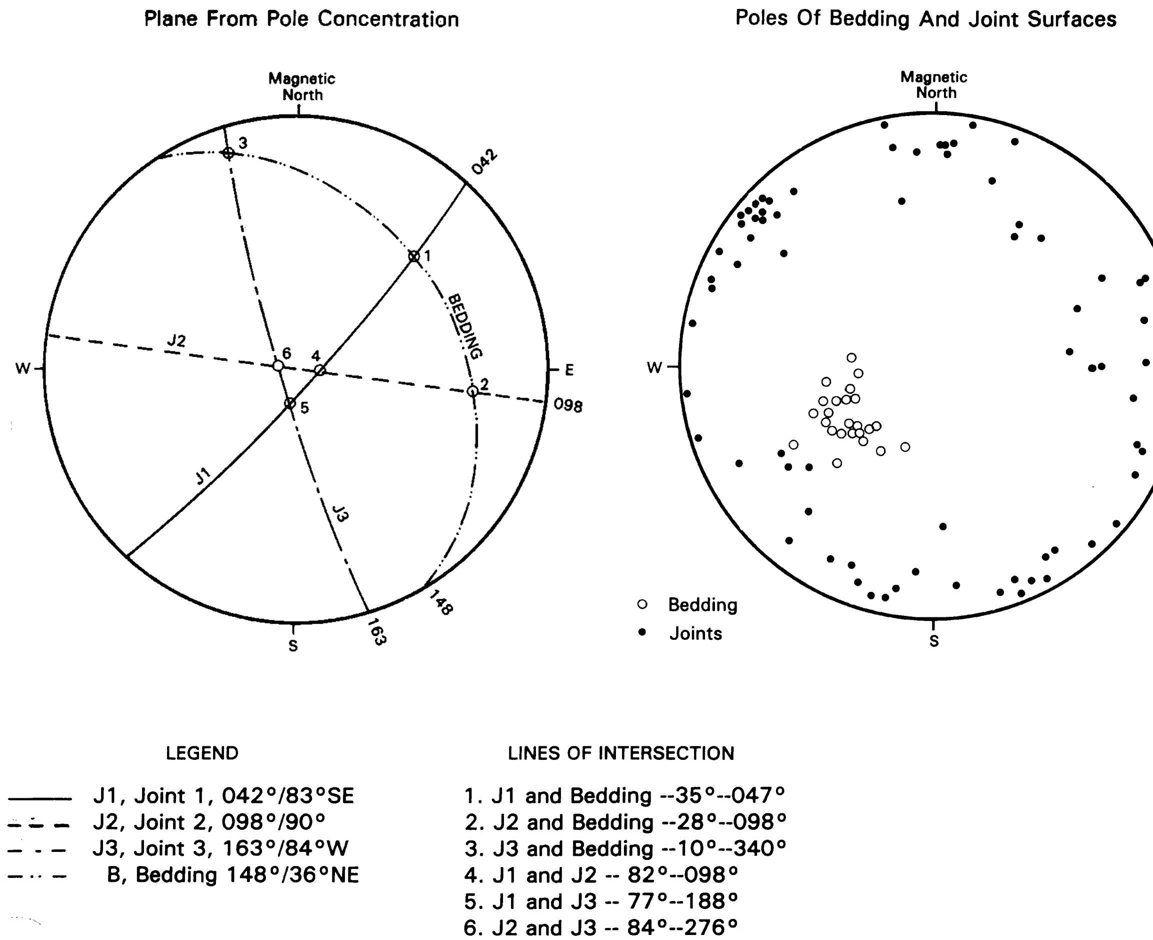

Figure 3. Equatorial equal-area stereonets of joint patterns at Hopewell Rocks (Jacques, Whitford and Associates Limited, 1987)

places by sand, gravel or mud. A discontinuous notch occurs at the cliff foot, and it is responsible for the characteristic mushroom-shaped appearance of most of the stacks. The smoothness of the floor and lower parts of the walls of the notches, and the occurrence of blankets of sand and gravel suggest that abrasion must be an important erosional process on the shore platform and at the cliff foot. Rock falls are caused by wave quarrying along joints and bedding planes at the foot of the cliff, and quarrying removes clasts from the conglomeratic cement, although the general lack of large debris, fresh erosional scars and the nature of the rock suggest that it is of limited importance on the shore platform.

Selby's (1980) classification was used to assess the stability and mass strength of the rocks in the cliff (Table I). This classification is based on the strength of the rock, joint characteristics and the flow of groundwater out of the rock. Unfortunately, the conglomeratic nature of the rock made it impossible to measure its compressive strength, but Schmidt Rock Test Hammer (SRTH) values indicate that the conglomeratic cement is physically very weak, although the clasts are much stronger. Nevertheless, when the other factors are considered, the classification suggests that the mass strength of the rocks ranges from moderate to high, and that they are slightly more resistant in the northern part of the area than in the south. It should be noted, however, that although the classification has reasonably accounted for differences in slope angles in terrestrial environments, it may not be as successful in marine environments where slopes are undercut by waves and other coastal mechanisms.

Several workers have discussed the effect of rock structures on the occurrence and orientation of specific coastal features, but there has been no attempt to assess the general strength of this relationship (Wilson, 1952).

Table I. Rock mass strength (Selby, 1980)

Schmidt Rock Test Hammer Value (SRTH)	10–35	$r=5$
Weathering at the cliff base	Unweathered to slightly weathered	$r=9$ to 10
Joint spacing	1 to 3 m to >3 m	$r=28$ to 30
Joint orientation (bedding planes)	horizontal in south; slight seawards dip (<20°) in north	$r=14$ in south; $r=9$ in north
Joint width	0 to 1 m	$r=5$ to 6
Joint continuity	Continuous, no infill	$r=5$
Outflow of groundwater	None	$r=6$
Total Rating		$r=72$ to 76 in the south; $r=67$ to 71 in the north

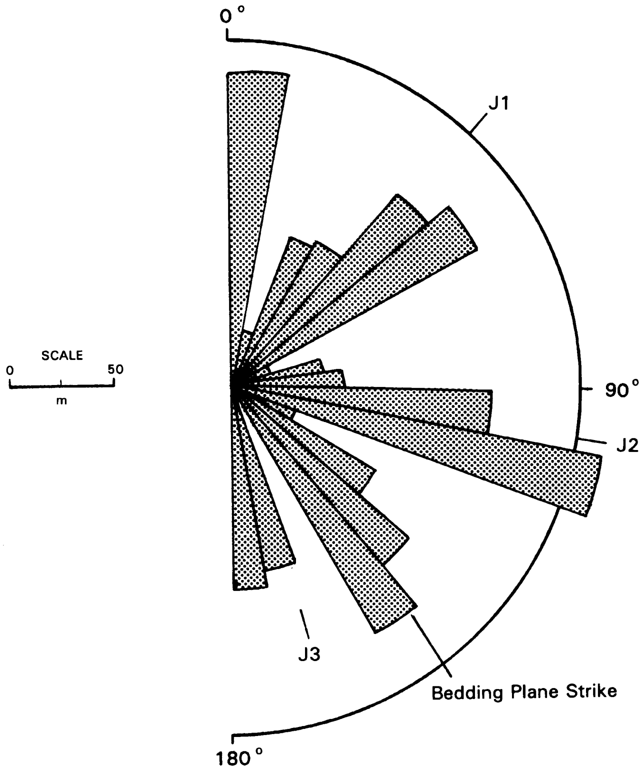

Figure 4. Cliff orientation (stippled rose diagram) and the orientation of joint and bedding planes

The orientation and length of each, approximately linear, section of the coast at Hopewell Rocks were measured to determine the degree to which coastal orientation is controlled by rock structure. It was found that most of this coast is aligned along the three major joint sets or along the strike of the bedding planes (Figure 4). Structural elements therefore control much of the coast, but a fairly large proportion run approximately north–south and are less clearly related to structural trends. This component is largely composed of cliffs at the back of bays, particularly in Castle Rock, Cutoff and Diamond Rock Coves in the southern part of the area. Although the J3 joint set could partly account for the orientation of some of this coast, the bays appear to be the result of much denser joint patterns than in the adjacent headlands, especially J2 joints, which are almost normal to the back of the bays.

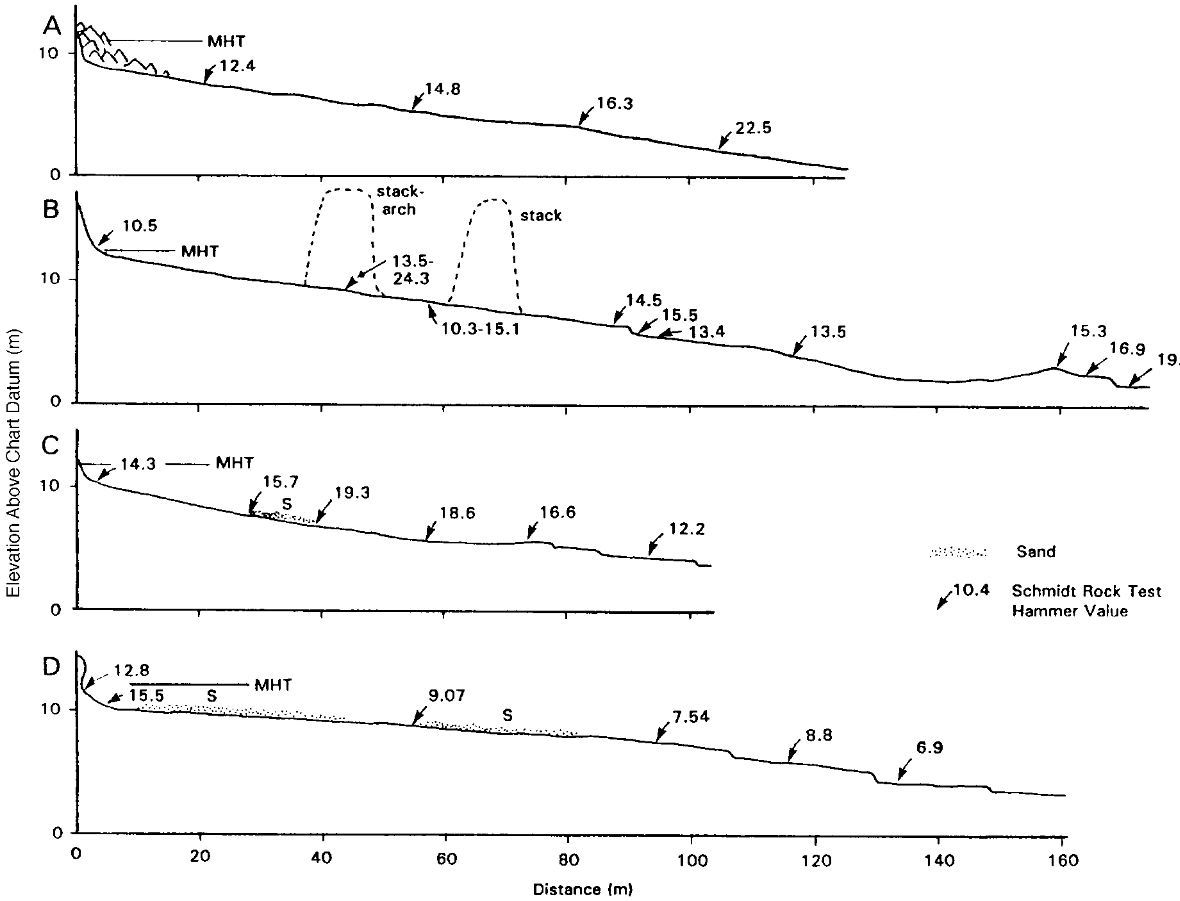

Figure 5. Examples of platform profiles and SRTH values. The location of the cliff platform junction for each profile (A,B,C,D) is shown in Figure 1.

MASS MOVEMENT

Mass movements in the cliffs and stacks of Hopewell Rocks are the result of instability caused by marine undercutting, frost action and possibly hydrostatic pressures exerted by water in steeply inclined rock clefts (Trenhaile, 1987). Mass movements originate at the intersection of joints and bedding planes, and the type of failure that takes place reflects the orientation and dip of the discontinuities. Most failures are the result of wave erosion and weathering along bedding planes and J2 joints oriented perpendicularly to the cliff. Intersection with J1 joints running parallel to the cliff face then creates large blocks of rock that are prone to collapse. Caves are formed by block subsidence or, if a series of blocks is involved, crevices extending up to the top of the cliff. Adjacent columns of rock may then topple into these crevices. Wedges of rock also collapse where two joint sets intersect in the cliff face. Most wedge-type failures take place along the intersection of joints J1 and J2, and joints J1 and J3 (Jacques, Whitford and Associates, 1987).

SHORE PLATFORMS

Despite some pockets of sand and gravel and thin veneers of mud, extensive areas of shore platform were exposed during summer in the central and northern parts of the area. The platform was surveyed with a level and staff and shown to have an essentially linear profile, although there are ridges and breaks of slope on outcrops of more resistant rock, and steps and troughs along eroded joint planes (Figure 5). Platform geometry was measured from the surveyed profiles, supplemented by data obtained from a detailed Autocad 12 map of the

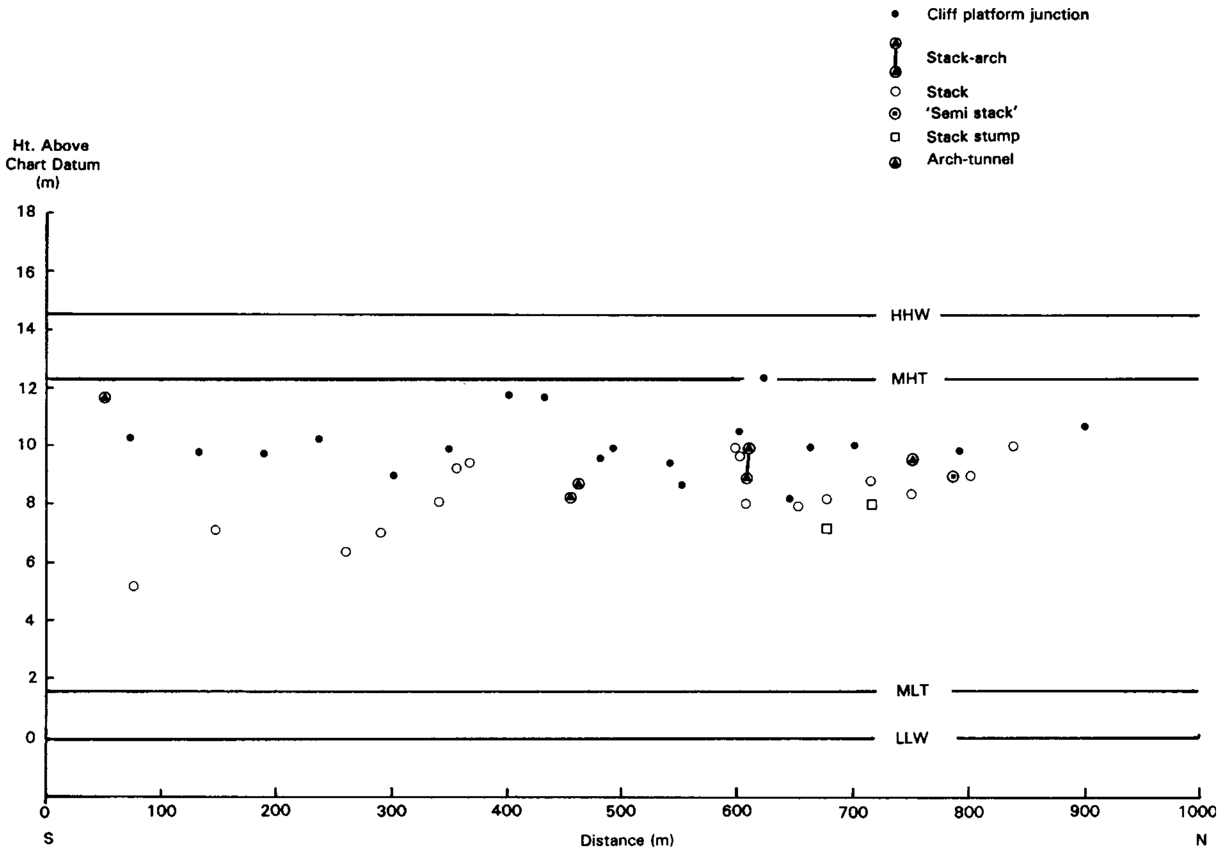

Figure 6. Stack-, stack-arch-, arch-tunnel and cliff-platform junction elevations in relation to specific tidal levels. Distances are measured from the southern limit of the study area

area, which has a contour interval of 1 m (New Brunswick Department of Natural Resources and Energy, Parks Branch, April 1991, file number Rock9010.exe). Mean platform gradient, defined as the average slope of the platform between the cliff–platform junction and the mean low tidal level, is 3·2°, although it varies from 3·5 to 4° in the central part of the area to about 2·5° in the north; the platform in the south is generally covered in thick accumulations of sand and gravel. Gradients are high in comparison with shore platforms in most other areas, but they are consistent with the general relationship that exists between platform slope and tidal range (Trenhaile, 1974, 1978, 1987, 1997). Similar gradients have been measured in the basalts and conglomeratic sandstones on the southern coast of the Bay of Fundy and, as expected, they are slightly greater than in macrotidal southern Wales, where the spring tidal range is about 10 to 11 m.

The elevation of the junction of the cliff and platform (the cliff–platform junction) is generally from about 1·5 to 2·5 m below the mean high tidal level (Figure 6). Although these junctions are low, relative to the high tidal level, they are consistent with SRTH values which suggest that the conglomeratic cement is physically very weak and therefore susceptible to abrasion and wave quarrying. The height of the cliff–platform junction also decreases with decreasing rock hardness in southern Britain (Wright, 1967; Trenhaile, 1972), possibly because lower and weaker waves are only able to erode the cliff foot in less resistant rocks.

Mean platform elevation was determined by measuring the horizontal extent of survey and map profiles between 0·5 m vertical intervals from the cliff–platform junction to the mean low tidal level. Previous theoretical and field work suggests that mean platform elevation increases with rock hardness (Kirk, 1977; Takahashi, 1977; Trenhaile and Layzell, 1981; Gill and Lang, 1983). Mean platform elevation at Hopewell Rocks tends to be greatest in weaker rocks, but this largely reflects the occurrence of outcrops of harder and weaker rock in different parts of the profiles rather than the effect of variations in mean rock hardness between profiles.

STACKS

Stacks form where portions of a retreating coast become isolated in bays or off headlands. Although there has been little research on their development, it has generally been assumed that they represent more resistant elements on eroding rock coasts. Some stacks are the result of differences in the resistance of the cliff to wave action owing, for example, to induration, longshore variations in rock type in folded or dipping strata, or the occurrence of dykes or other hard volcanic material (Trenhaile, 1987). Most stacks, however, are probably separated from the mainland by erosion along joints, faults and other planes of weakness that allow water to penetrate the rock mass. Erosion and enlargement of the discontinuities by mechanical wave action, physical and chemical weathering and bioerosion cuts up the rock into sections, whose shape and size are determined by the pattern and density of the planes of weakness.

There are therefore essentially two types of stacks: those that are more resistant, for lithological or structural reasons, than the mainland; and those that consist of the same material as the mainland and are separated from it along discontinuities. Joint density, the width of promontories and other geological and topographical factors determine the initial size and shape of stacks. The morphology of a stack and the strength of its rock determine how long it can survive, whereas the resistance of the rock in the mainland determines how far a stack can become isolated offshore before it is destroyed. Stacks can be a long way from shore if they consist of rocks that are much more resistant than in the mainland, and because of their age and downcutting on the adjacent platform, their base is usually continuously submerged. Another factor that determines the longevity of a stack is whether erosion is largely by wave-driven mechanisms or by chemical weathering or bioerosion. In the former case, erosion can operate effectively only on the seaward side of the stack, whereas in the latter case, erosion can act more equally on all sides.

The roughly rectangularly shaped stacks of Hopewell Rocks occur in bays and off headlands. Large numbers of SRTH measurements were made on these stacks, on the limbs of the stack-arch, on the adjacent shore platform and at the cliff foot to determine the possible effect of variations in rock hardness. A minimum of 20 measurements was made at each sampling site, which represented an area of approximately $0{\cdot}1\,m^2$. It was found that harder rock at the base may have contributed to the formation of the southern limb of the main stack-arch (8) and the adjacent stack (7) immediately to the south (Figures 2 and 7). Otherwise, the rocks are no more resistant in stacks and in the stack-arch than in the adjacent platform and cliff, and in some cases they are even weaker. Most stacks, arch-tunnels and caves at Hopewell Rocks result from dissection of the rock mass along prominent joint planes, rather than from differences in rock hardness. Development of these features in this area is facilitated by the occurrence of J1 and J2 joint sets that are roughly parallel and perpendicular to the coast, although several arch-tunnels have formed along J3 joints, including the stack-arch, and they frequently define the sides of stacks and promontories. Although mud, sand and other material on the platform sometimes made it difficult to follow joints very far, single joint planes could be traced between and alongside one or more stacks, before running into the cliff in a cave, crevice or tunnel (Figure 1).

Old photographs have been used by a number of workers to assess the rate of development and destruction of stacks and arches (Shepard and Kuhn, 1983). Several photo-surveys have been undertaken at Hopewell Rocks to monitor the state of the cliff and to prevent the development of potentially dangerous rock falls. Although these records are quite detailed, the oldest was only made in the early 1980s (Jacques, Whitford and Associates, 1987). This record consists of more than 100 photographs covering all of the cliff, stacks and arch-tunnels in the study area, and in many cases it shows the same feature from several different angles. Portions of the cliff are in a state of continuing erosion and destabilization, especially in the coves, but these photographs suggest that little change has occurred over much of this coast in the last 12 to 16 years. Nevertheless, only a low stump remains today of a stack that was a short distance seawards of stack 11 (Figure 1) in 1983, and it has been reported that another collapsed in 1988–1989 in Cutoff Cove (Jacques, Whitford and Associates, 1989). The photographic evidence therefore suggests that one or two stacks are destroyed about every 12 to 16 years. Therefore if one stack is eroded every 16 years, all 16 of the stacks at Hopewell Rocks will collapse within the next 256 years. Alternatively, if two stacks are destroyed every 12 years, all 16 stacks will be destroyed in only 96 years. If it can also be assumed that stacks are replaced at approximately the same rate as they are being removed, then the evidence implies that the 16 stacks at Hopewell Rocks have developed in the last 96 to 256

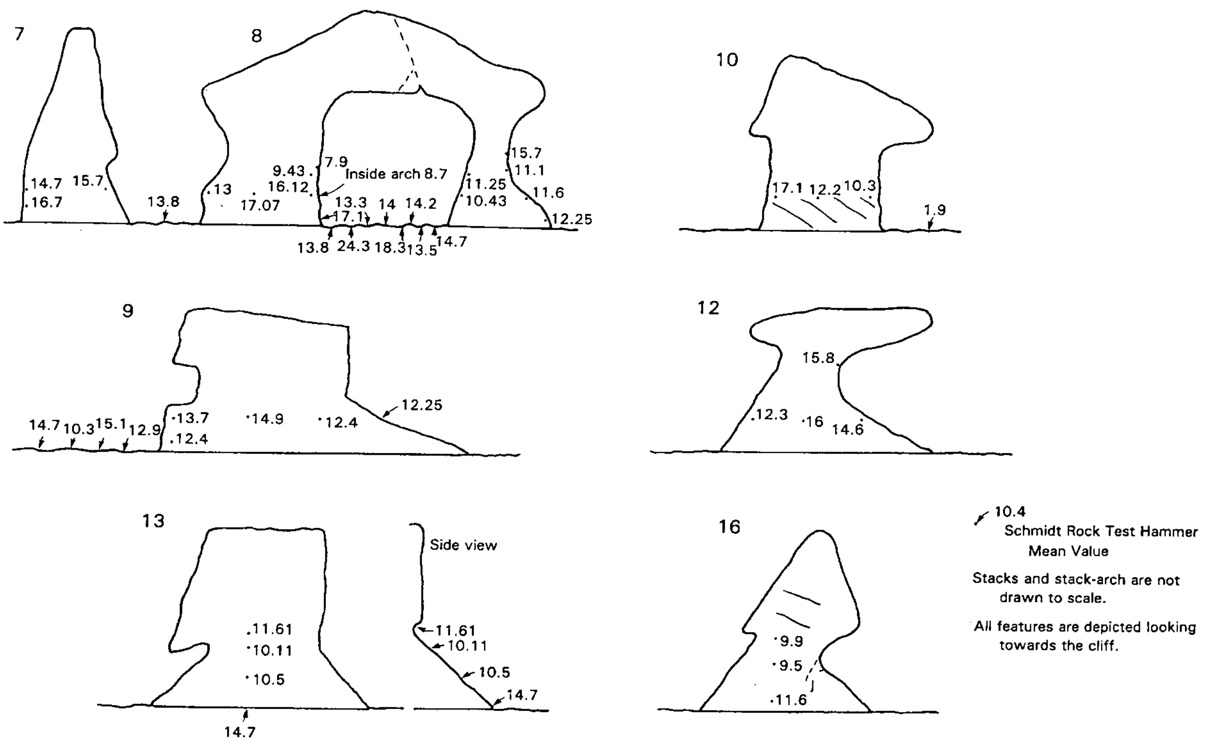

Figure 7. Mean SRTH values on stacks and on stack-arch 8

years. These estimates are based on the assumption that wave and weather conditions, and therefore rates of stack erosion, are fairly constant through time, and that the stacks at Hopewell Rocks represent a wide range of developmental stages. Because of these assumptions, calculated rates of erosion and development can only be considered to provide a rough guide to rates of stack development, but they do appear to be reasonable based on the photographic evidence and the occurrence of several future stacks that are in various stages of detachment from the cliff.

Stacks develop through erosion and dissection of the cliff base. The foot of the cliff is usually at, or close to, the high tidal level, although it varies according to geological factors and differences in exposure to wave attack (Trenhaile, 1972, 1978, 1987). When they are first formed, the elevation of the base of most stacks is similar to the cliff–platform junction, but with continued cliff retreat and platform lowering, the foot of stacks must be reduced gradually to lower elevations in the intertidal zone. Therefore, as stacks become older there must be an increase in the horizontal distance from the retreating cliff, and in the vertical distance between the stack–platform junction and the cliff–platform junction. The Hopewell stacks are detached along joints, and as they consist of the same rocks as on the mainland, erosion rates are similar. The stacks are unable to survive for long periods and they are therefore generally restricted to positions within about 20 m of the cliff. The base of most stacks is only from 0·5 to 2 m below the cliff–platform junction, and although they range from below the mid-tidal level up to about 2 m below the mean high tidal level, the foot of most stacks is in the high mid-tidal zone, although there is a slight increase in elevation towards the north (Figure 6).

NOTCHES

Notches are ubiquitous at the foot of the cliff, and they are responsible for the characteristic mushroom-shaped appearance of the stacks. To measure the notches, a photographic slide was made of the profile of each notch, using a levelling staff, which was placed in a vertical position at the front of each notch, to provide scale. The slides were then projected onto a grid to facilitate measurement of the vertical and horizontal dimensions of the

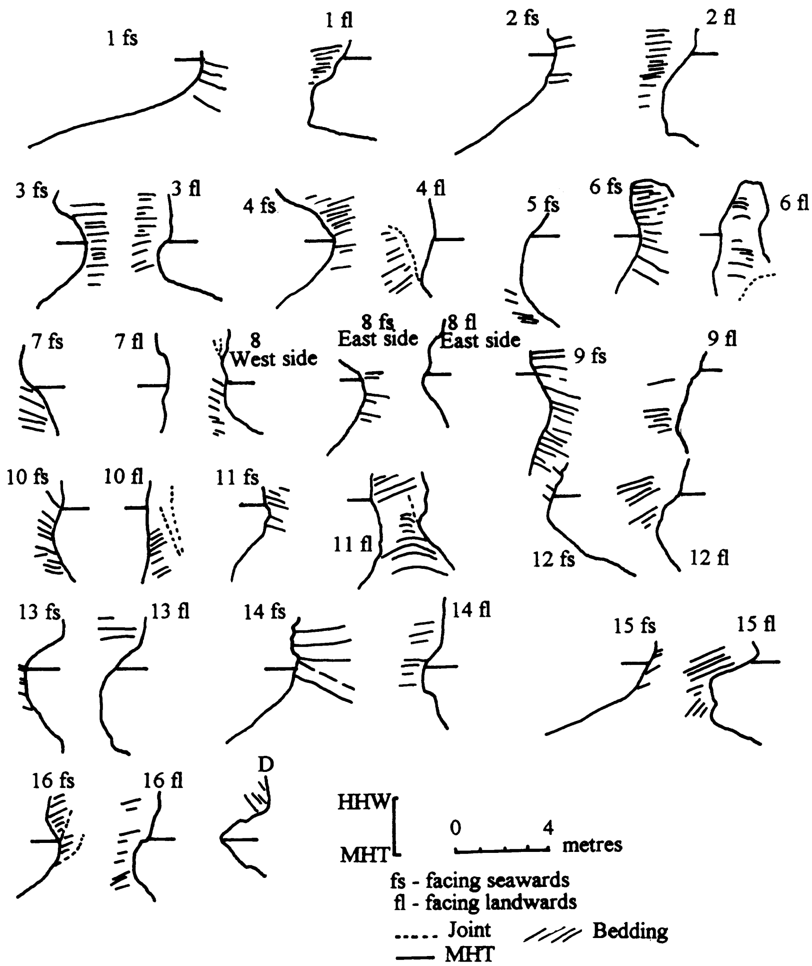

Figure 8. Notch profiles. The identification numbers correspond to those used in Figure 1

notches. Notch profiles were measured in this way at the cliff foot, at the base of the stacks and at the foot of the stack-arch and several arch-tunnels (Figure 8).

In comparison with the deep, vertically narrow notches of tropical microtidal coasts, the notches of Hopewell Rocks are broad and fairly shallow, although their shape is frequently modified by rock dip and accelerated marine erosion of thin argillaceous beds. The greatest notch depth, measured from the perpendicular to the lip of the notch overhang, is less than 2·5 m, and there is no consistent relationship between the depth of notches on the seaward and landward side of stacks. Although this might suggest that waves are not the primary erosive mechanism, this is countered by the fact that the deepest part of the notches is consistently at higher elevations on the seaward than on the landward side of stacks. Furthermore, although it was sometimes difficult to determine the position of the top of each notch, most extend to greater elevations on the seaward than on the landward sides.

The lack of any consistent difference in the depth of notches on either side of stacks is not because of similar rates of erosion, but because of the restrictions placed on notch depth by the strength of the rock and its ability to stand unsupported. When a notch has attained its maximum depth, as determined by the structure and strength of the rock, further erosion causes the roof to collapse, leaving the lower part as a ramp-like structure at the foot of the stack. More rapid undercutting and more frequent collapse events on the seaward than on the landward

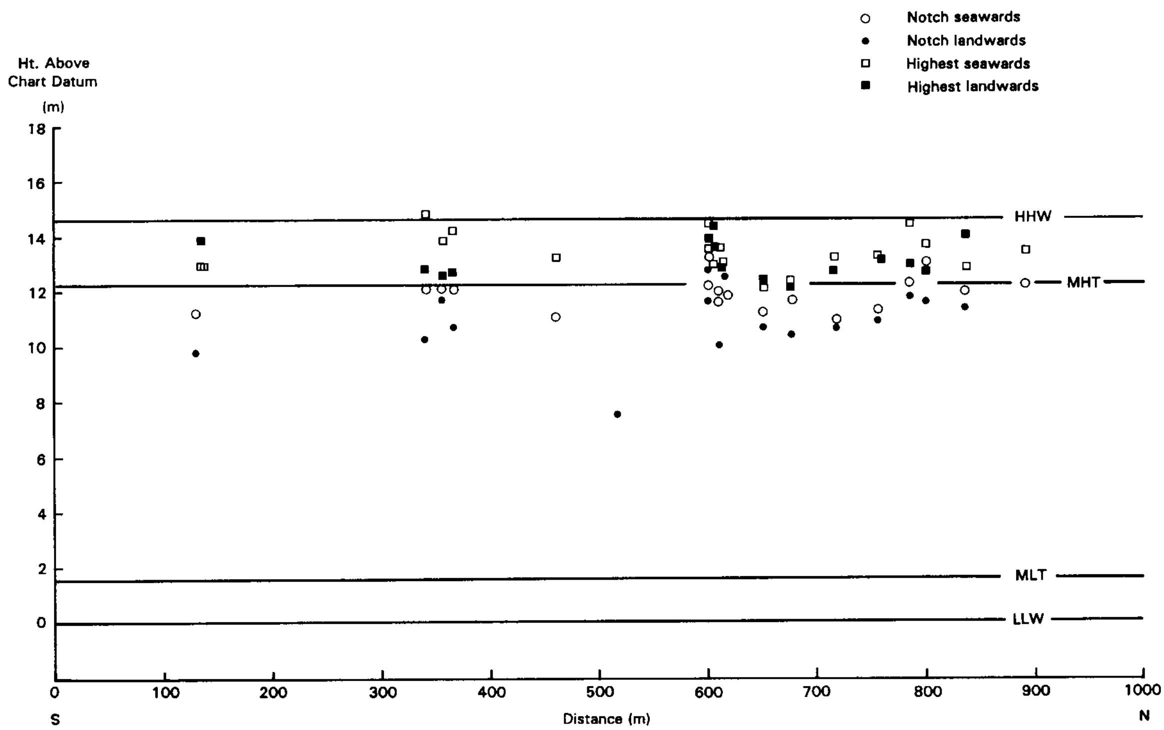

Figure 9. The relationship between the deepest and the highest parts of notches and tidal levels.

side of stacks are therefore reflected in the presence of wider and more numerous ramps on the exposed side, rather than in deeper notches. Ramps are generally absent on the landward side of stacks, and even where they are present they are almost always narrower than on the seaward side. The length of the ramps suggests that, given the present depth of the notches, most stacks have experienced one or more undercutting and collapse events on the seaward side. On the other hand, only one stack (3) appears to have experienced more than one collapse event on the landward side, although narrow ramps suggest that there may have been one small collapse event on the sheltered side of two others (1 and 2).

The deepest part of most notches is a little below the mean high tidal level, although a few are up to 1 or 2 m below it, especially on the landward side of stacks (Figures 8 and 9). The highest portion of some notches extends up to the higher high water level, but most are between the higher high and mean high tidal levels. Maximum wave pressures are exerted close to sea level, and this is also the area in which mechanical wave erosional processes are most effective. Wave erosion, over the long periods of time commensurate with the development of rock coasts, must therefore be greatest at or close to the elevation most frequently occupied by sea level, which is around the mean neap high and low tidal levels (Trenhaile, 1987, 1997). The occurrence of notches 1m or so below the mean high tidal level is therefore consistent with the tidal duration hypothesis, which suggests that the vertical extent and profile shape of the notches are also governed by the amount of time the water surface is at each elevation.

Although notches develop fairly close to the high tidal levels, they have a similar relationship with the adjacent platform, most occurring within 2 to 4 m of the foot of the stacks (Figure 10). Although abrasion and water hammer associated with broken storm wave uprush may contribute to notch development on stacks, the height of these notches above the platform surface suggests that they are primarily the result of mechanical wave erosional processes operating at the high tidal level. There is a significant inverse relationship at Hopewell Rocks between the height of the notch above the stack base and the height of the platform at that point (Figure 11). This suggests that as stacks become increasingly isolated from retreating cliffs, the difference in the elevation of the notch and the adjacent platform increases as the platform is lowered. The notch, which is

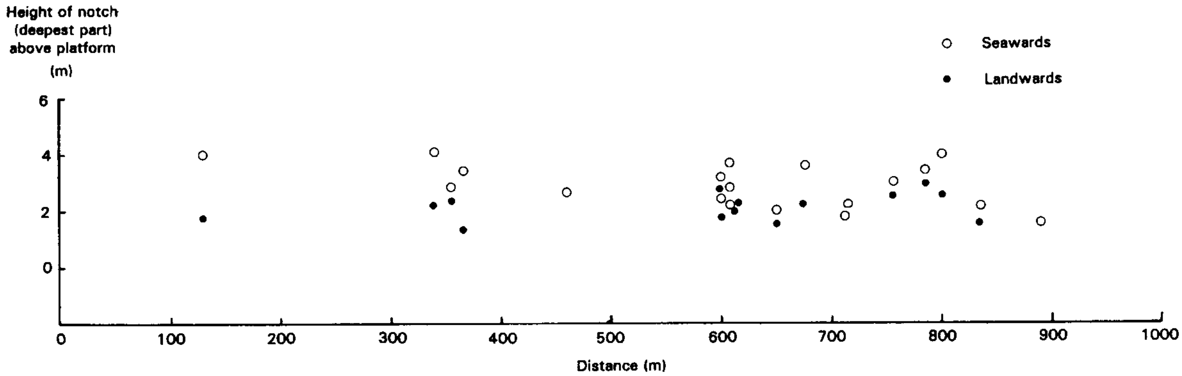

Figure 10. The height of the deepest part of notches above the adjacent platform

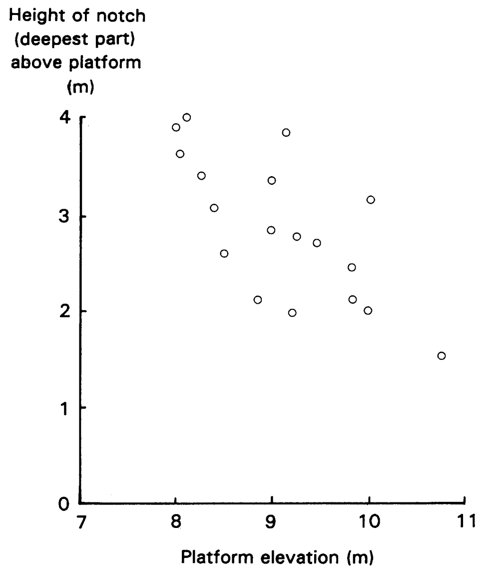

Figure 11. Seaward-facing notch height above the adjacent platform plotted against platform elevation ($r^2=0{\cdot}5$)

initially just above the cliff–platform junction at the high tidal level, therefore appears to rise up the stack, although it is the base of the stack that is actually becoming lower (Figure 12). This suggests that as stacks increase in age and the notches rise above the platform surface, abrasion, which can operate in notches at the cliff foot and near the base of newly formed stacks, is gradually replaced by wave quarrying and other mechanical wave erosional processes that are more closely associated with the water surface. Changes in the dominant notch-forming processes through time may have implications for the relationship between notch elevation and tidal levels.

Notches can only begin to develop on the landward side of stacks after they have been separated from the cliff. Landward notches also develop more slowly than notches on the seaward side of stacks, which are exposed to the full force of the waves. Therefore, deep notches would generally occur only on the landward side of fairly old stacks, which have long ramps and possibly deep notches on their seaward sides. The general relationship which appears to occur between the depth of the notch and ramp on the landward and seaward sides of stacks provides some support for this hypothesis (Figure 13). The main exceptions to this relationship are stack 3, which has a wide ramp on the landward side, and, to a lesser extent, stack 13, where the notches on the landward and seaward sides are of similar depth.

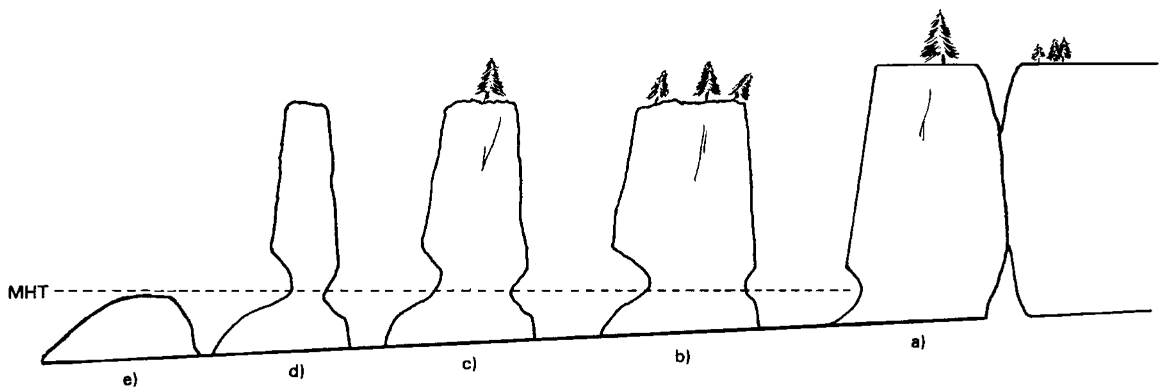

Figure 12. Proposed evolution of Hopewell Rocks stacks through stages (a) to (e), as they become increasingly isolated from the cliff

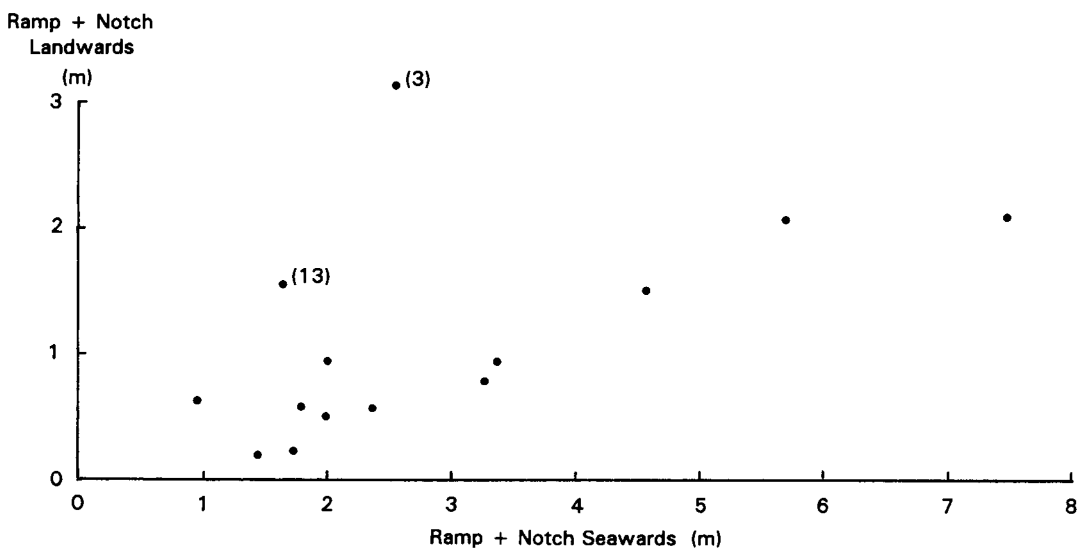

Figure 13. The relationship between ramp and notch depth on the landward and seaward sides of stacks.

It has been estimated, based on photographic evidence, that stacks at Hopewell Rocks can survive for approximately 100 to 250 years. This suggests that stacks, which are initially between 4 and 8 m wide normally to the coast, are undercut through notch erosion at rates of about 1.6 to 8.0 cm a^{-1}. These rates are based on the assumption, however, that erosion and notch formation only occur on the seaward side of stacks. Furthermore, stacks become top-heavy and topple over when their pedestals are too narrow to support them, and the last few metres of rock are therefore not undercut. Assuming that minimum pedestal width is 1 to 2 m, and that erosion of the seaward side of stacks is between 1·5 and 3 times faster than on the landward side, actual rates of notch erosion on the exposed seaward side would be between about 0·5 and 5·25 cm a^{-1}.

The increasing difference in elevation through time between the deepest part of stack notches and the base of the ramp may also provide a rough estimate of rates of platform lowering in the upper portions of the intertidal zone. The deepest parts of most stack notches are between 2 and 4 m above the surrounding platform surface, whereas the equivalent figure for the younger notches at the cliff base is about 1 to 2 m. This suggests that in the last 100 to 250 years, the upper portion of the platform surface has been lowered at rates ranging from 0 to 30 mm a^{-1}. Similar figures, ranging from 2 to 20 mm a^{-1}, are obtained based on the 0·5 to 2 m difference in the elevation of cliff–platform junctions and stack–platform junctions. Although these estimates can only be

considered to be crude approximations, calculated rates of platform lowering at Hopewell Rocks are consistent with downwasting rates measured elsewhere (Sunamura, 1973; Kirk, 1977; Trenhaile, 1987).

CONCLUSIONS

Although stacks and arches are spectacular components of many rock coasts, there has been little study of their distribution and development, in part because of their low numbers and often because of their inaccessibility. The mushroom-shaped stacks that are in various stages of development in the intertidal zone at Hopewell Rocks provided an excellent opportunity to study stack form and evolution in a macrotidal environment. Stacks have developed on a shore platform whose gradient and other aspects of its morphology are closely associated with the tidal range, although variations in rock hardness are also significant. The stacks have largely formed through dissection of the rock mass along joints, which also control the general orientation of the cliff. The elevation of these stacks and the form and depth of the notches suggest that as a stack becomes increasingly isolated from the cliff, notch formation and collapse produce a ramp on the exposed seaward side of the narrowing stack. Although the elevation of the notch continues to be close to the high tidal level, where tidal duration is at its maximum, it occurs increasingly higher up the stack as the adjacent platform surface is lowered. Further notch development causes the remaining portion of the stack to collapse, forming an asymmetrical pedestal or stump that will eventually be reduced to the general platform surface. Stack characteristics therefore reflect their stage of development, according to their changing position in the intertidal zone, the degree of detachment from the cliff and their age (Figure 12). The degree to which stacks in less extreme tidal environments develop in a similar way to those in the Bay of Fundy remains to be determined.

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